

Real-Time Graphics Architecture

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<http://www.graphics.stanford.edu/courses/cs448a-01-fall>

The OpenGL[®] Graphics System

Outline

- Introduction and history
- Block diagrams
- Goals and approaches
- Details
- Successes
- Mistakes
- Lessons
- Future

The OpenGL® Graphics System

Web sites

- www.opengl.org
- <http://oss.sgi.com/projects/ogl-sample/>
- www.sgi.com/software/opengl/license.html

OpenGL is a registered trademark

- Owned by Silicon Graphics
- Must be used as an adjective!
- This is all SGI owns now

OpenGL is controlled by the “ARB”

- Architecture Review Board
- Named by Bill Glazier after Palo Alto’s board ☺

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OpenGL ARB Members

1991	Compaq (Digital Equipment Corporation)
	IBM
	Intel
	Microsoft
	Silicon Graphics
1994*	Evans & Sutherland
	3D Labs (Intergraph)
1995*	Hewlett Packard
1996*	Sun Microsystems
1998	nVidia
1999	ATI
2001	Apple

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* Estimated

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Some of the 70+ OpenGL Licensees

3D Labs	Intellgraphics
Apple	Interdimension
ATI	Intergraph
AT & T	Japan Radio Company
Barco	Microsoft
Be Inc.	Miro
Cirrus Logic	Mitsubishi
Compaq	NEC
Cray Research	nVidia
Daikin	RasterOps
Digital Equipment Corp.	S3
Elsa	Samsung
Evans & Sutherland	Siemens Nixdorf
Fujitsu	Silicon Graphics
Harris Computer	Sony
Hewlett Packard	SPEA
Hitachi	Sun Microsystems
Hummingbird Communications	Template Graphics Software
IBM	Univel
Intel	

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History of OpenGL

1977*	Jim Clark writes -LDS for E&S Multi Picture System
1982	Silicon Graphics incorporated
1983	IRIS GL ships with IRIS 1000 terminal
1985*	IRIS GL licensed to IBM
1986*	Jim Clark and others propose SGL (Simple GL)
1987	SGI and Pixar consider joint API development IRIS GL extended with vector commands (e.g. v3f)
1988	SGI ships GTX and Personal Iris
1989	First GL 5.0 documents
1990	OpenGL development begins SGI and Microsoft graphics collaboration begins
1991*	OpenGL ARB created

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History of OpenGL (cont.)

- 1992 OpenGL 1.0 completed (June 30)
 OpenGL / PEX debate (panel) at SIGGRAPH '92
 OpenGL course at SIGGRAPH '92
- 1995 OpenGL 1.1 completed
- 1996* OpenGL specification is made public
 SGI ships OpenGL DLL
- 1997 Fahrenheit agreement between SGI and Microsoft
- 1998 OpenGL 1.2 completed
- 1999* Apple becomes an OpenGL licensee
- 2000 OpenGL becomes available as open source
- 2001 OpenGL 1.3 completed

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SGI / Pixar Collaboration

"It seems to me that we are trying to merge troff and Scribe into a single hodge-podge. I don't think that we'll get a good result if we continue."

"It seems that a key to a high-performance interface is choosing the right boundary between what and how. ... Even the Pixar language has this boundary in it. It still does not support a description like 'lighted like a sunday afternoon in september'."

"I am in touch with Pat Hanrahan. He will send me an updated copy of a document outline today. I am to be working on what I discuss in this note. What next?"

-- Kurt Akeley (to Forest Baskett)

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Fahrenheit

SGI promoting and supporting PC OpenGL

Microsoft asserting control of their own platform

Fahrenheit is the negotiated settlement

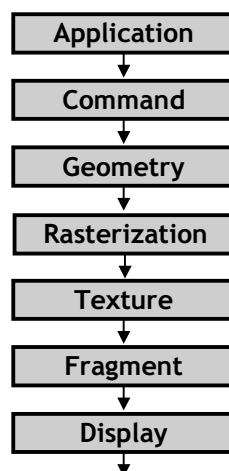
Results:

- Broad reach of agreement failed
 - No new low-level standard, little at scene graph level
- OpenGL still exists on all Windows platforms
- SGI learned a lot about Microsoft's business
- Microsoft learned a lot about graphics
 - Seamus's presentation at Graphics Hardware 2001
- Kurt got mean, stopped dealing with Microsoft

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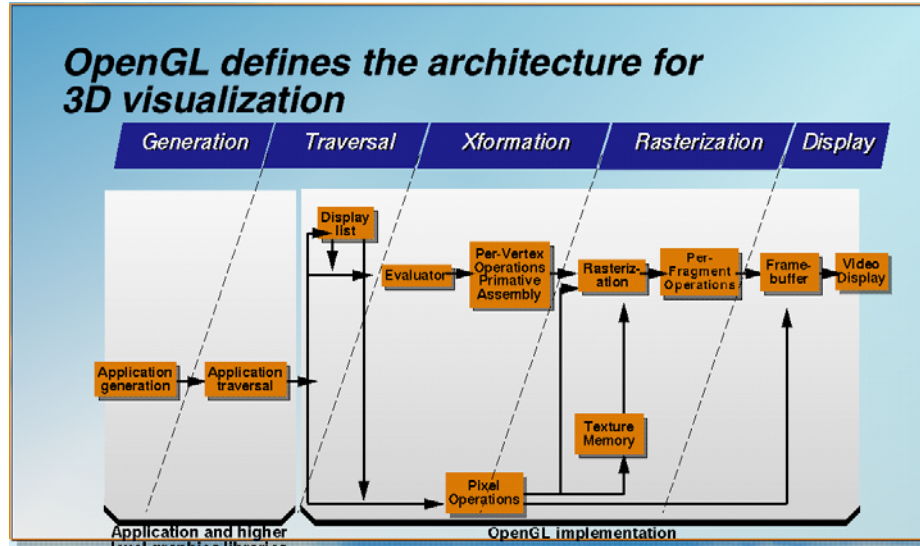
Modern Graphics Pipeline



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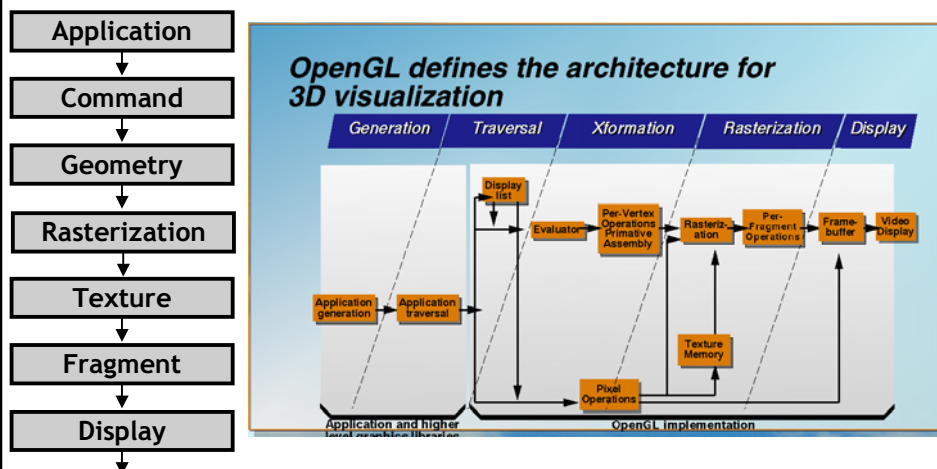
Typical OpenGL Block Diagram



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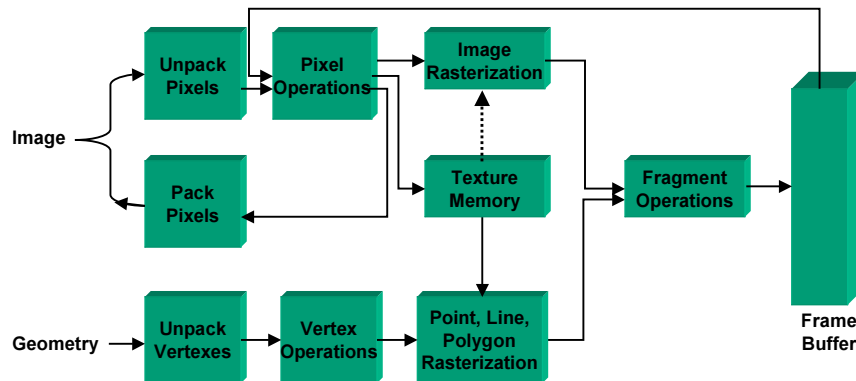
They match



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My Favorite OpenGL Block Diagram

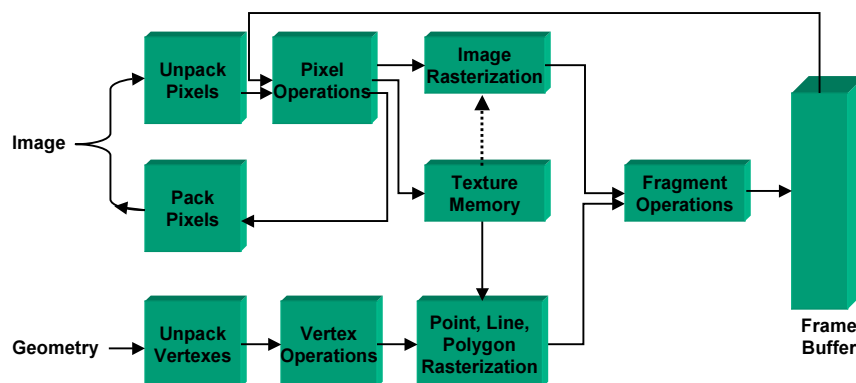


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My Favorite OpenGL Block Diagram

Symmetry of geometry and imaging paths
Circulation paths



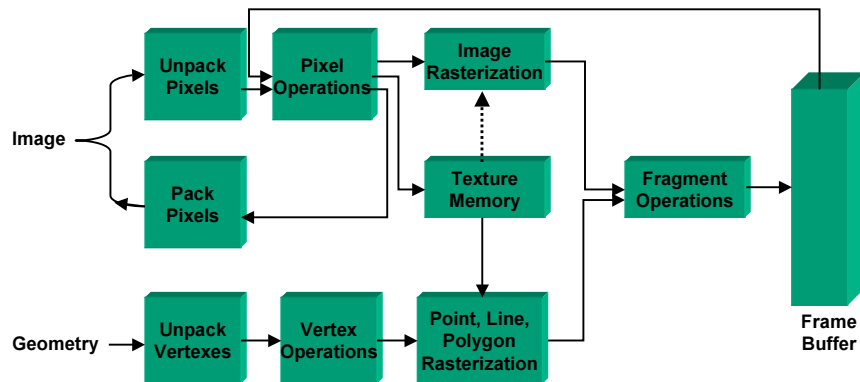
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My Favorite OpenGL Block Diagram

Orthogonal operation

- Vertexes, pixels, fragments, texture



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Goals

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Goals for OpenGL

Industry-wide acceptance
Consistent implementations
Innovative implementations
Innovative and differentiated applications
Long life
High quality

Non-Goals

Make graphics programming easy

- OpenGL is a power tool

Integrate digital media and 3D graphics

- This is really hard

Goal: Industry-wide acceptance

Avoid compromising performance

- Allow explicit application trade-offs

Get it right the first time

- Make minimum changes from IRIS GL
- Collect lots of input during design
- Do implementation during design

Create an open standard

- Licensing program
- ARB to control future evolution of specification

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Goal: Industry-wide acceptance (cont.)

Achieve compatibility with multiple

- Operating systems (MS, Unix, Linux, Mac OS, OS/2, Be, ...)
- Window systems (X, Windows)
 - Framebuffer not part of OpenGL state
- Programming languages (C, FORTRAN, Java, ...)
 - No pointers, structures, function overloading
 - No 2D arrays at interface (row-major / column-major)

Target Microsoft acceptance

- Omit 2D, window interface, font support
- Allow full application compliance with Windows
- Issue: no driver interface specified

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Goal: Industry-wide acceptance (cont.)

Marginalize PEX

- API, not protocol, is the right interface
- But client-server matters too
 - Defined GLX protocol
 - Included server-side display list storage
 - Carefully specified client-side state

Match current hardware capabilities

- Get input from other IHVs

Meet current application needs

- Get input from ISVs

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Goal: Consistent Implementations

Tightly written specification

Conformance tests and required verification

Complete implementations

- No sub-setting of 1.*n* specification
- Minimum resource specifications

Required runtime error semantics

- Check and report
- No other side effects

Incentives to share extensions

- Balance desires for consistency and for innovation

Result: portable applications

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Goal: Innovative Implementations

Specification not too tight

- Not pixel-exact
- Smooth antialiasing loosely defined
- Object storage abstracted
- Filter attached to texture image

Extensibility

- Key to IHV innovation
- Requires IHV control of entire driver
 - Obvious for systems companies
 - Not at all obvious for Microsoft

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Extensibility

SGL maintains registry

- Over 270 extensions so far
- Names, token values, GLX protocol, ...

Careful extension documentation

- Extension specification template
- Syntax rules for names
- Suffix/prefix rules
 - Clearly identify all non-core commands and tokens
- Extension numbers
 - Must account for all lower-numbered extensions
 - OpenGL is more than the sum of its parts

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Extension Template

Name	Additions to the GLX Specification
Name Strings	GLX Protocol
Version	Dependencies (details)
Number	Errors
Dependencies (list)	New State
<i>Issues</i>	■ Get Value
Overview	■ Get Command
New Procedures and Functions	■ Type
New Tokens	■ Initial Value
Additions to Chapter [2,3,4,5,6]	■ Attribute Set
	New Implementation Dependent State

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Extension Syntax Rules

Required abbreviations

Abbreviations specifically not allowed

Compound words

Naming rules

- General
- Procedures (e.g. verb-noun or adjective-noun)
- Defined constants (all caps, underbars)
- Parameters ([0], 1, 2, <target>, <params>)
- Extensions (prefixes, suffixes)

Parameter order and typing rules

Suffix codes

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Extension Categories

Proprietary

- Use corporate prefix/suffix, e.g. SGI

EXT

- Use EXT prefix/suffix
- Must be implemented by at least two licensees

ARB

- Use ARB prefix/suffix
- Specification controlled by the ARB

1.n

- No prefix/suffix
- Specification controlled by the ARB

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Goal: Innovative Applications

Consistent implementations / tight specification

Design qualities

- Mechanism, not “features”
- Orthogonality
- Circulation
 - Similarity of pixels and texels
 - “Machine Shop” analogy
- Sufficiency of capability (e.g. stencil)

Invariance specification

- Support multi-pass algorithms

Intuitive usability

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Goal: Long Life

Extensibility

Anticipate important trends

- Integration of image processing and 3D graphics

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Goal: High Quality

Beauty counts

SGI culture, very different from Microsoft!

Avoid design-by-committee

- Build a horse, not a camel

Correct well-known IRIS GL deficiencies

- No command prefixes
- Can't be used by libraries (incomplete save/restore)
- Error reporting via printf() !

Provide documentation

- Specification
- Man pages
- Programming guide

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Some Details

Object Ids

- Support display list “editing”, scripting

Evaluation parameter semantics

- Allow evaluation to share vertex engine(s)

Direct render to texture

- Would constrain memory optimization

Sifdv interface

- For application convenience and efficiency

Discourage incremental matrix arithmetic

- No pre-multiply
- Stack provided for “undo”

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Some Details (cont.)

Application-specified clipping done in eye coordinates

- Allow use of singular projection matrixes

Unit area pixels and texels

- Matches window system notion of pixel ownership
- Makes frustum and viewport calculations obvious
- Makes texture wrapping arithmetic obvious
- Matched pixel and texel addressing supports circulation

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Success With Respect to Goals

Industry-wide acceptance

- Great for Unix, Linux, embedded systems
- Good as can be expected with Microsoft ☺
- Poor for game consoles

Consistent implementations

- Good for core features
- Marginal for new features

Innovative implementations

- Industry and academic standard
- Interesting work-arounds for constraints

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Success With Respect to Goals (cont.)

Innovative and differentiated applications

- Very successful

Long life

- Almost a decade so far

High quality

- Generally respected
- Story of Carmack endorsement

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Technical Successes

Procedural interface

- “Every graphics systems aspires to have a procedural interface”

Generalized texture capability

- All primitives (with pixel texture extension)
- Various dimensions of texture
- Texel and pixel conformance
- Incremental in-place modification
- Explicit format, filter specification, MIP level, ...
- Texture matrix

Formalization of fragment

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Mistakes

Business

- Taking our eye off Microsoft

Technical

- Display lists as encapsulation for “objects”
 - Re-introduction of texture objects
- Overly-abstract storage management
 - Proxy-priority middle ground is not tenable
- No “fast path” clues in API
 - Too much faith in pure mechanism
 - E.g. DL objects, window position, 2D transform, in-place framebuffer to texture memory transfer, ...
- Persistent parameter state between Begin/End
 - But would have broken IRIS GL programs badly

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Mistakes (cont.)

Probably should have been omitted

- Texture borders!
- Edge flags
- Polygon antialiasing
- Color index features (lighting, antialiasing, ...)

Needlessly complex or wrong

- ColorMaterial()
- Normal transformation
- Texture wrap semantics
- Bit fields

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Lessons

It is worthwhile to specify carefully

- Write the spec first, or you'll be sorry!

It is critical to guide system implementers and application developers to a common understanding of how to support and achieve high performance.

Beware Microsoft

People make and evolve standards

- Invest in developing a culture
- Keep competitive issues out of a specification's controlling body.

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Future of OpenGL

On the rebound

- Low period in the late 90s

Provides alternative to DirectX/Microsoft API control

Apple commitment is a positive sign

Programmability is an exciting development

- Fits well in OpenGL structure
- OpenGL may truly be a “library” some day

Lots of 2.0 activity, ARB still functioning

Tenth birthday next summer

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